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System Checkout of the 155-mm Short-Barreled Howitzer Using Telemetry Projectiles

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Firings were conducted in a unique 155-mm short-barreled howitzer to check out the structural integrity of the redesigned support mounts for the weapon. The howitzer system was designed to be advantageous in acquiring pressure and acceleration data from instrumentation onboard the projectile by using simple hardwire techniques with no intricate projectile redesign or expensive telemetry components. Data from the firings is presented both on the telemetry and the system integrity.

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PREFACE

The U.S. Army Ballistic Research Laboratory was deactivated on 30 September 1992 and subsequently became a part of the U.S. Army Research Laboratory (ARL) on 1 October 1992.

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1. INTRODUCTION

An ongoing and important function of the Interior Ballistics Division (IBD), U.S. Army Ballistic Research Laboratory (BRL), is to provide accurate simulations of the interior ballistic performance of weapon systems (Baer and Frankle 1962). Using the experimental performance measured during a gun firing, an uncomplicated lumped-parameter code such as the IBHVG2 (Anderson and Fickie 1987) can be used to predict nominal values of projectile displacement, velocity, acceleration, and pressure data for slight changes in projectile weight, charge weight, propellant web, parasitics, etc.

With the increasing complexity of both projectile design and propellant formulation and geometry, ballistic simulations have to more accurately predict the interior ballistic performance. In the past, poorly defined parameters such as burning rates and resistance-to-motion were manipulated until satisfactory simulations were achieved. With more complex codes, these parameters have to be accurately determined through experiments.

Initial results on quantifying resistance to projectile motion (resistive pressure) and the governing logic and equations have been documented (Ruth and Evans 1983) at BRL using a specially constructed short-barreled howitzer. The advantages of such a system were reduced muzzle velocity, making projectile and onboard projectile instrumentation easier to recover; easy access to the nose of the projectile for hard-wire instrumentation; simple electronics with hard-wire telemetry; and no intricate nose scoop for collecting the wire from the gun bore. As noted in Ruth and Evans (1983), the resistive pressure can be defined and calculated by using the data from interior ballistics measurements as indicated below:

$$P_f = P_b - \frac{(w \bullet a)}{(g \bullet A)} , \tag{1}$$

where P_f = Engraving and resistive pressure

P_b = Pressure acting on base of the projectile

a = Acceleration of the projectile

A = Cross-sectional area of the bore

w = Projectile weight

g = Acceleration due to gravity,

and from the Lagrangian correction for base pressure knowing breech pressure,

$$P_b = P/(1 + c/2w) \, , \tag{2}$$

where P = Breech pressure

c = Propellant weight

w = Projectile weight .

If one measures the base pressure directly using telemetry, the above assumption for calculating base pressure does not have to be made, and a more accurate representation of the resistive profile can be obtained.

In order to expand the understanding of propellant burning during the ignition and early combustion phase for new concepts in propellant design, a 155-mm short-barreled howitzer, similar in concept to the aforementioned 105-mm howitzer, was designed and constructed at BRL. During initial experiments, the howitzer mount was damaged because of higher than expected chamber pressures (pressure continued to rise after projectile exited from tube and was transversing finger support mounts) and possible structural (hidden) flaws in the steel. Repeated firings apparently weakened the side support struts connecting the howitzer to the recoil system. After a redesign and repair was done, the howitzer was field-tested for system structural compatibility.

To enlarge upon the 105-mm howitzer database (Ruth and Evans 1983), a very simple hard-wire telemetry system was devised for the checkout firings of the redesigned howitzer in an attempt to gain onboard data in a projectile fired from a higher velocity 155-mm system. Both the 105-mm and 155-mm systems were similar in that the projectile extended out the front of the gun bore so as to simplify hard-wire telemetry hookups. Although the telemetry hookups in the 155-mm projectiles were fairly fragile for these acceleration loads, the inexpensive setup and the onboard data that might be recorded justified the attempt to record the onboard pressure and acceleration data.

2. TEST COMPONENTS

2.1 Fixture Construction and Assembly. The modified 155-mm M185 howitzer tube used for launching projectiles; the method for attaching the tube to the modified M155 howitzer tube so that a standard M174 recoil mechanism could be used; the technique for measuring onboard pressure and acceleration during early projectile motion; as well as the method of recovering expelled, extinguished propellant after ignition and early combustion for chemical and physical analysis were all BRL innovations. Fabrication of the component parts for the howitzer and gun interfaces was done at the U.S. Army Combat Systems Test Activity (CSTA) machine shop.

A diagram of the 155-mm short-barreled howitzer is shown in Figure 1. Projectile travel was about 100 mm rather than the 5,098 mm in a standard howitzer. Assembly of this unique weapon was accomplished in several stages (refer to Figure 1 to match components to the following letters in parentheses). First, the breech and shortened tube from a standard M185 howitzer (A) were threaded into a unique breech ring assembly (B) which was in turn welded to a M155 tube (C) by a steel interface union (D). The distance (E) between the breech of the 155-mm tube and the rear plate of the steel interface union was long enough to allow any 155-mm projectile to be loaded into the short-barreled howitzer. The rear plate of the interface union (D) was connected to an adapter (F) which slipped over the bore of the 155-mm howitzer (C). The instrumented projectile (G) when seated in the howitzer had its noseplate and forward ogive outside of the gun tube, thereby minimizing hard-wired hookup complexities. By using this system, the 155-mm short-barreled howitzer could be fired using the standard recoil of a M174 mounted in the upper carriage from a 155-mm M59 gun. Excessive muzzle blast from the weapon was well in front of the recoil and equilibrator systems and would thus cause no structural damage.

The shortened M185 howitzer tube was instrumented at three locations with Kistler 607C3 pressure gages as shown in the schematic of Figure 2. Gages were located in the breech spindle, two each (Pl and Pr), two each (P3l and P3r) at 13.0 cm from the rear face of the tube (RFT); two each (P4l and P4r) at 13.4 cm from the RFT; and one each (P5) at 13.8 cm from the RFT. To accurately measure ignition delay and record data online, the standard lanyard-operated, spring-driven firing pin was replaced by a gas-activated firing pin (Rocchio, Hartman, and Gerri 1979). The gas necessary to drive the modified firing pin into the M82 percussion primer was obtained from an M52A3B1 electric detonation cap.

2.2 Projectile Design and Gage Mounting Technique. Two inert 155-mm M101 projectiles were modified by sawing them approximately 36 cm from the base of the projectile into two sections. The interior hemispherical base surface of each projectile was then machined to a flat, cylindrical surface for mounting the hard-wire telemetry assembly. After machining, drilling, and threading the projectile base for mounting bolts to hold the telemetry assembly, the two parts of each projectile were welded back together.

The telemetry packages consisted of a housing assembly containing two piezoelectric transducers. Each of the housing assemblies was fabricated in three parts (see Figure 3 to match components to the following letters in parentheses). The pressure section (A) contained a pressure gage (B) mounted to measure the projectile base pressure as well as the mounting assembly to attach this section to the projectile body with the mounting bolts. The PCB pressure transducers used for the two tests were Model 109-M31 set for a top step of 140 MPa and Model 109M19 with a top step of 275 MPa. The acceleration section (C), which was threaded to the pressure section, contained an acceleration gage (D) isolated from hot propellant gases. In addition, a steel plug (E) was threaded to the top of the acceleration cavity to protect the gage from the projectile filler material. The PCB Piezontronics accelerators used for the two tests (Model 305A03) were set for a top step of 10,000 G's (98.2 km/s/s). The electrical leads from the pressure and acceleration gages were threaded through holes drilled in the two assembly sections. The leads were loosely looped in the body of the projectile and then threaded through a hole drilled in a wire capture scoop. Prior to threading the capture scoop into the fuze adapter, the projectiles were filled with high-temperature wax so that each projectile would match the weight of current HE rounds. The telemetry wires on the outside of the projectile were tied to a lug on the capture scoop to prevent them from being pulled free from the gages in the projectile. During firing setup, this data link was drawn taut forward of the projectile and secured to the radar reflector stand mounted directly in front of the howitzer. This technique aligned the telemetry wires with the axis of the howitzer during firing and hopefully would allow the projectile scoop to preserve the data link during the interior ballistic cycle.

2.3 Ammunition Components. For the two firings in this test, a low-pressure M4A2 Zone 5 charge and a high-pressure M203 Zone 8 charge were used. The main reason for using these two zoned charges was to completely check the design strength of the modified gun. It was realized that these acceleration loads would stress the limits of the hard-wire telemetry link and possibly destroy the data links early in the ballistic cycle.

3. RESULTS AND CONCLUSIONS

The short-barreled 155-mm howitzer was test-fired at two different rates-of-loading using the M4A2 Zone 5 and M203 Zone 8 charges. No adverse effects to the redesigned mounting structure supporting the 155-mm short howitzer to the 155-mm standard howitzer were observed, and the system is again functional for ongoing research experiments in the BRL. Although the inexpensive hard-wire data links for obtaining base pressure and accelerometer functioned for both charge loadings, the links broke very early in the ballistic cycle for both charges.

The results of the two firings are noted in Table 1. Plots of spindle pressure and Doppler radar, onboard base pressure and Doppler radar, and onboard acceleration and Doppler radar, all as a function of time, are shown for the Zone 5 firing in Figures 4–6, respectively. For the Zone 8 firing, the same series of plots are shown in Figures 7–9, respectively.

For the Zone 5 charge, peak spindle pressure was 70 MPa at 102 ms. The telemetry data links for both onboard projectile pressure and acceleration did not survive the entire interior ballistic cycle. Onboard base pressure was 52 MPa and spindle pressure was 65 MPa when the data link broke. During the engraving cycle for the metallic rotating band, an initial acceleration peak of 3.9 km/s/s was observed at approximately 1 cm of projectile motion. As the projectile went through the engraving process, the acceleration rapidly decayed to zero acceleration at approximately 1 cm of travel. After engraving was completed, the acceleration rapidly increased. At an acceleration of 14.7 km/s/s, the data link broke. Using the Equations 1 and 2, and setting the resistive pressure (P_f) to zero, a "no loss" maximum acceleration can be calculated. This calculated acceleration (30.6 km/s/s) assumes no energy was expended in the engraving of the rotating band or bore friction between the band and gun bore and would be higher than the measured peak onboard acceleration.

For the Zone 8 firings, heat from propellant gases affected most of the gages as noted by the baseline returns below the zero baseline. If the heat occurred late into the ballistic cycle, the maximum peak pressure would not be affected. Onboard base pressure reached 40 MPa before the data link broke. During the engraving cycle, an initial acceleration peak of 15.7 km/s/s occurred just as the projectile seated itself into the forcing cone. As it moved through the forcing cone, there was a peak engraving load of 15.72 km/s/s with a momentary pause just after engraving. Then the acceleration increased rapidly to a peak of 41.2 km/s/s before the data link broke. Again, this was much less than the calculated "no loss" acceleration of 113.5 km/s/s.

Using the onboard pressure-time and acceleration-time data from the online data acquisition and Equations 1 and 2, a resistive pressure-vs.-displacement plot can be generated at both zone levels, as

Table 1. Projectile, Charge, and Firing Data

	Round 1	Round 2
Projectile Weight (kg)	44.01	44.01
Charge Type	M4A2, Zone 5	M203, Zone 8
Gage Position	Pressure (MPa) [Time] (ms)	Pressure (MPa) [Time] (ms)
Spindle (left)	74 [100.9]	301 [48.2]
Spindle (right)	70 [100.9]	298 [48.2]
P3 (left)	67 [100.5]	220 [47.9][c]
P3 (right)	65 [100.5]	235 [47.9][c]
P4 (left)	66 [100.5]	235 [47.9][c]
P4 (right)	66 [100.5]	235 [47.9][c]
P5	67 [100.5]	240 [47.9]
Peak Base Pressure before telemetry link was lost	50 [98.8]	40 [47.8]
Acceleration (km/s/s)	—	—
Onboard peak engraving	3.9 [94.8][a]	15.7 [45][a]
Peak acceleration before telemetry link was lost	14.7 [98.5]	41.2 [46]
No loss (calculated)	30.6 [100][b]	113.5 [48.2][b]
Muzzle Velocity (m/s)	—	—

[a] Value of onboard peak acceleration during rotating band engraving (see plots).
[b] Value of calculated peak acceleration using peak spindle pressure, gun, and projectile inputs from the formula given in the text.
[c] Plots indicate heat to these pressure gages at some time in the ballistic cycle.

shown in Figures 10 and 11. Although the telemetry data links are broken early in the ballistic cycle, the peak engraving pressure and some of the resistive pressure is detailed. Both the character and level of the curves are in agreement with the data generated from data (Evans 1985) telemetered from full-up gun firings.

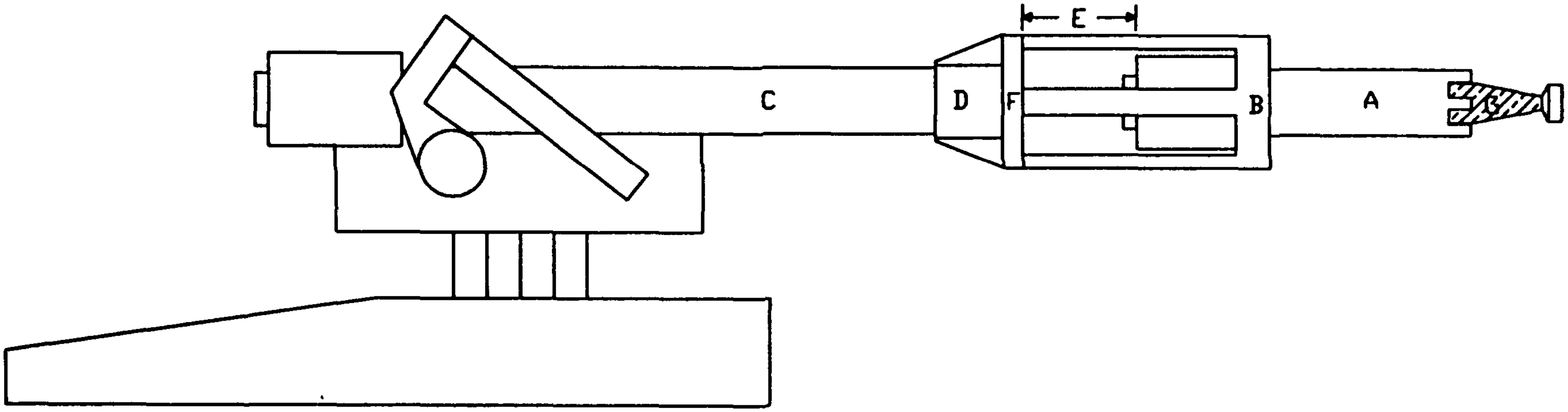

Figure 1. Modified 155-mm Short-Barreled Howitzer.

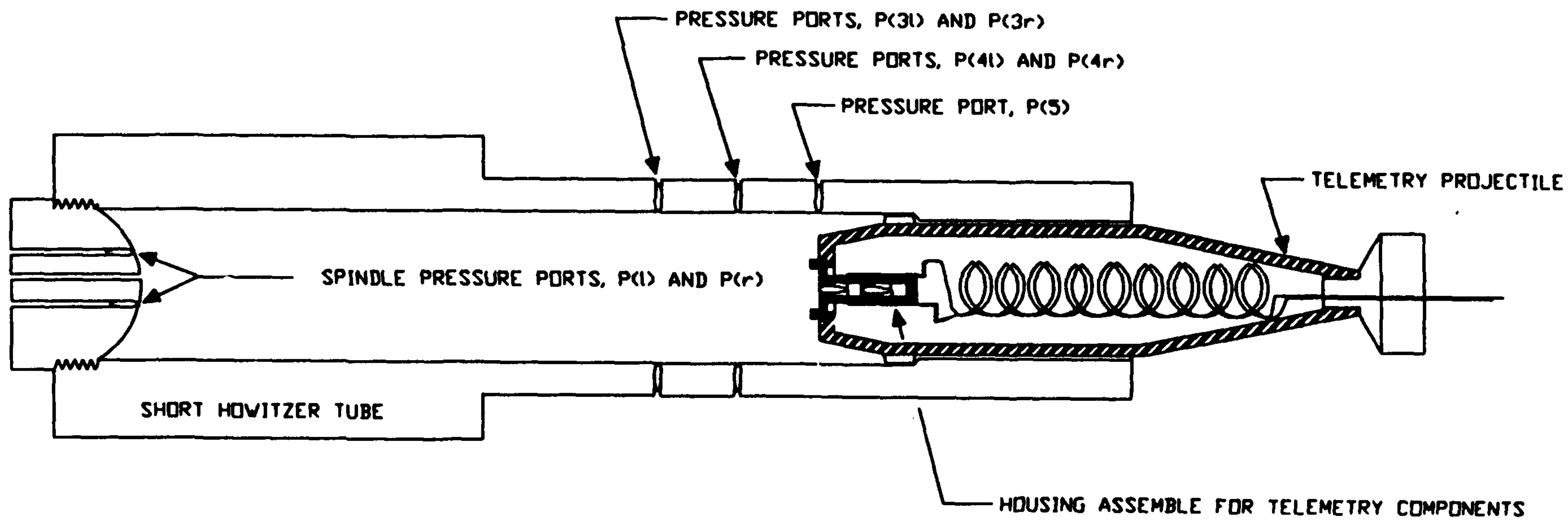

Figure 2. Modified 155-mm Howitzer Tube.

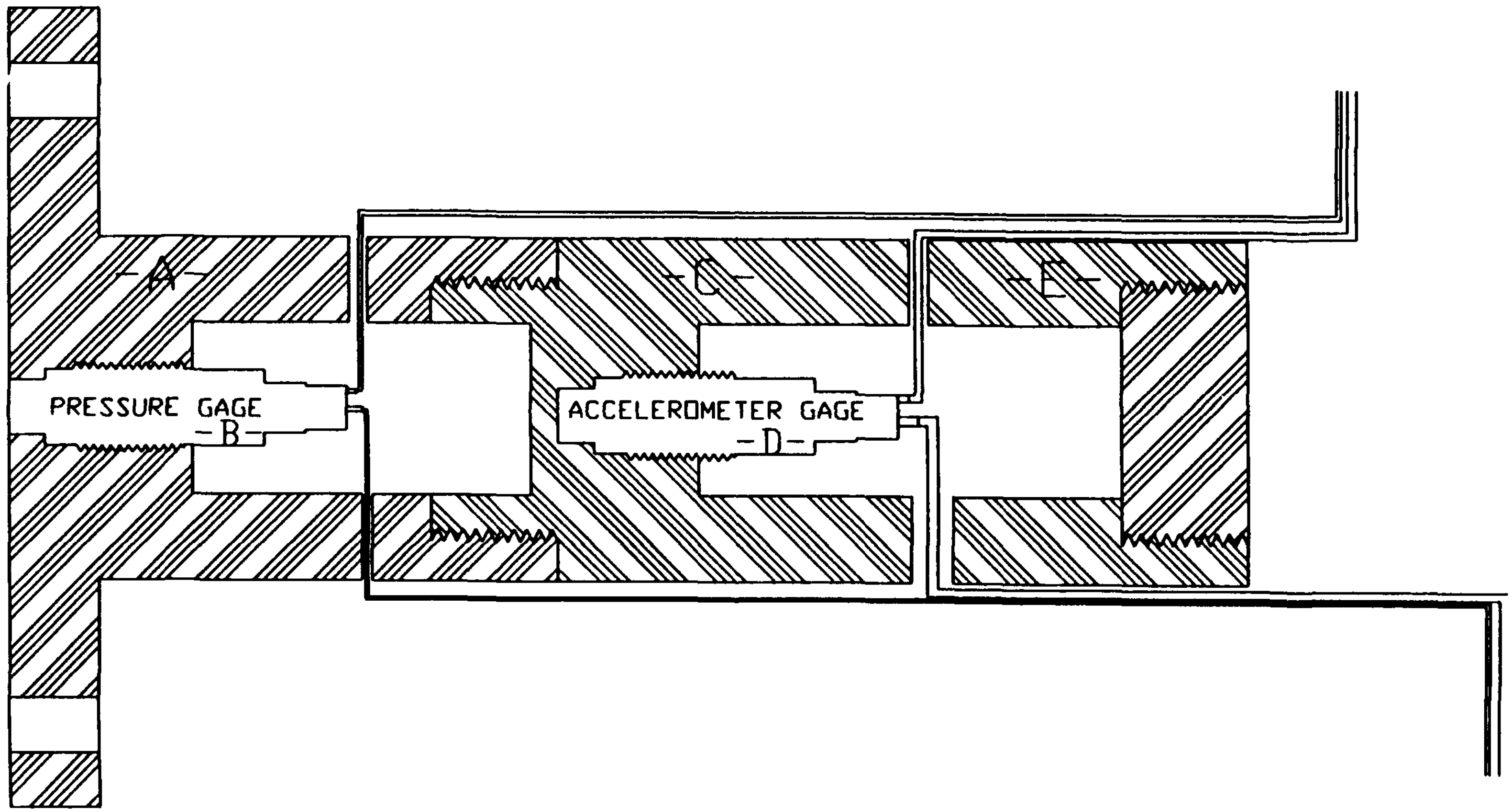

Figure 3. Housing Assemblies for Telemetry Components.

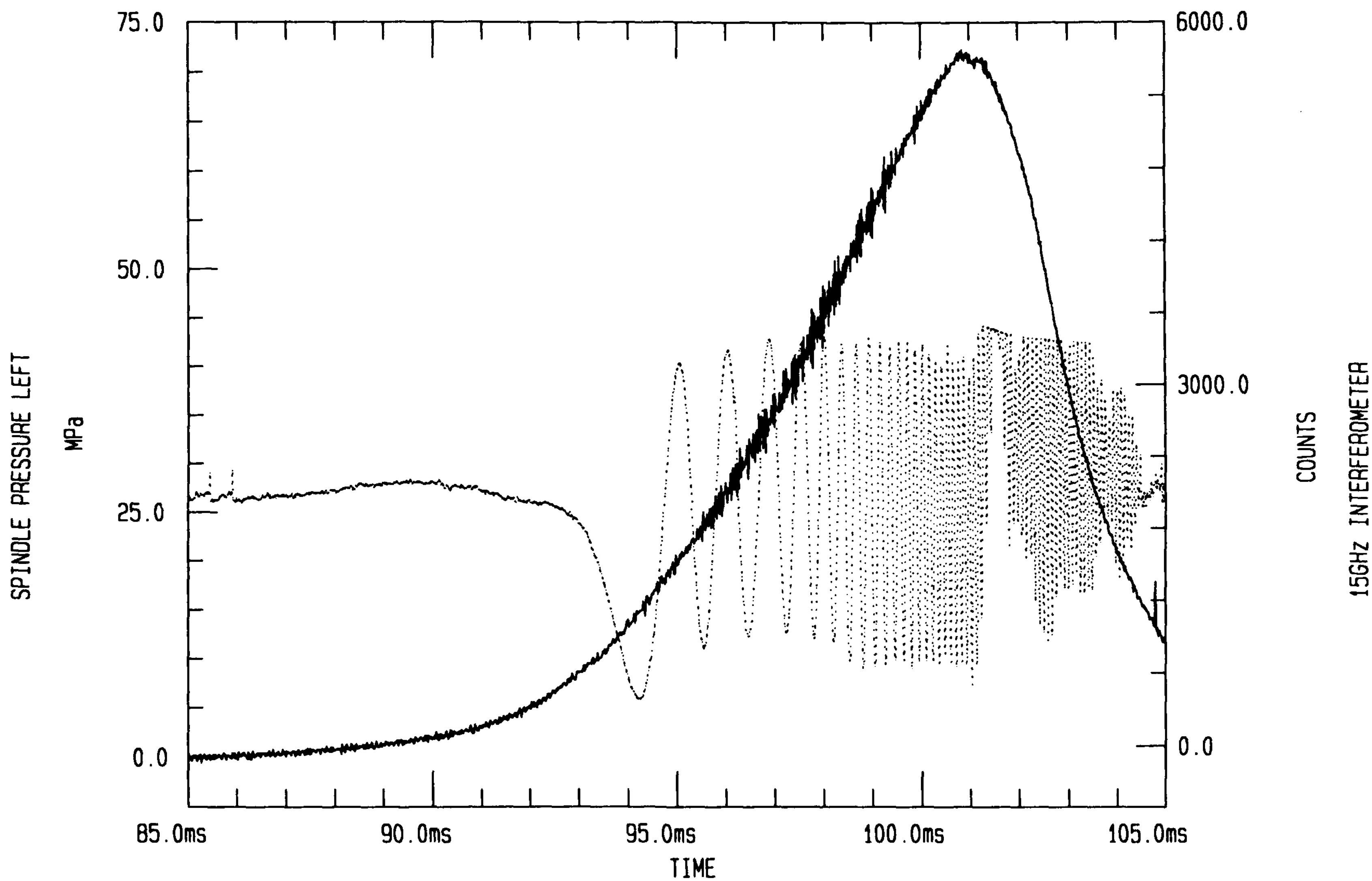

Figure 4. Spindle Pressure and Doppler Radar, Zone 5.

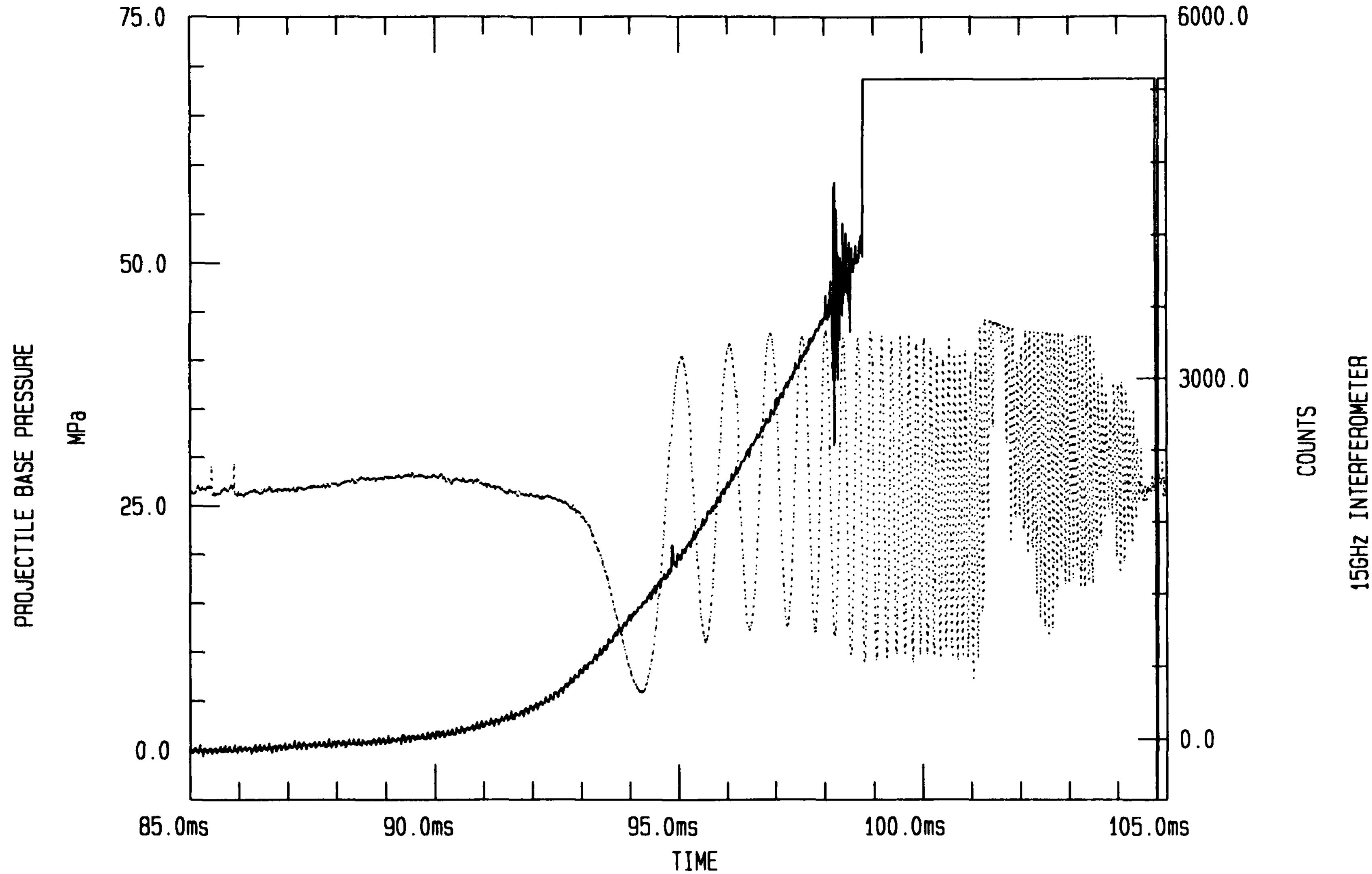

Figure 5. Onboard Base Pressure and Doppler Radar, Zone 5.

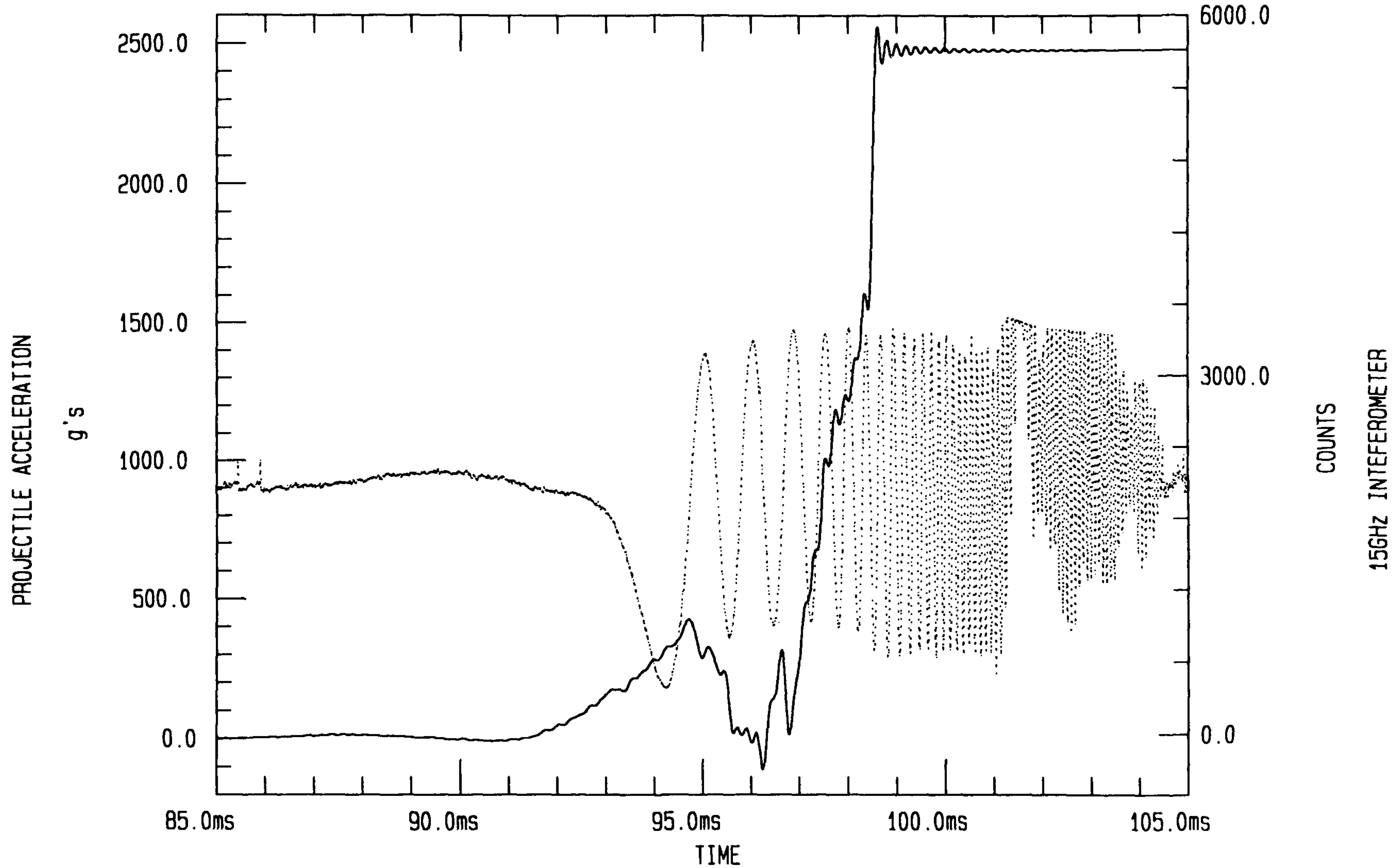

Figure 6. Onboard Acceleration and Doppler Radar, Zone 5.

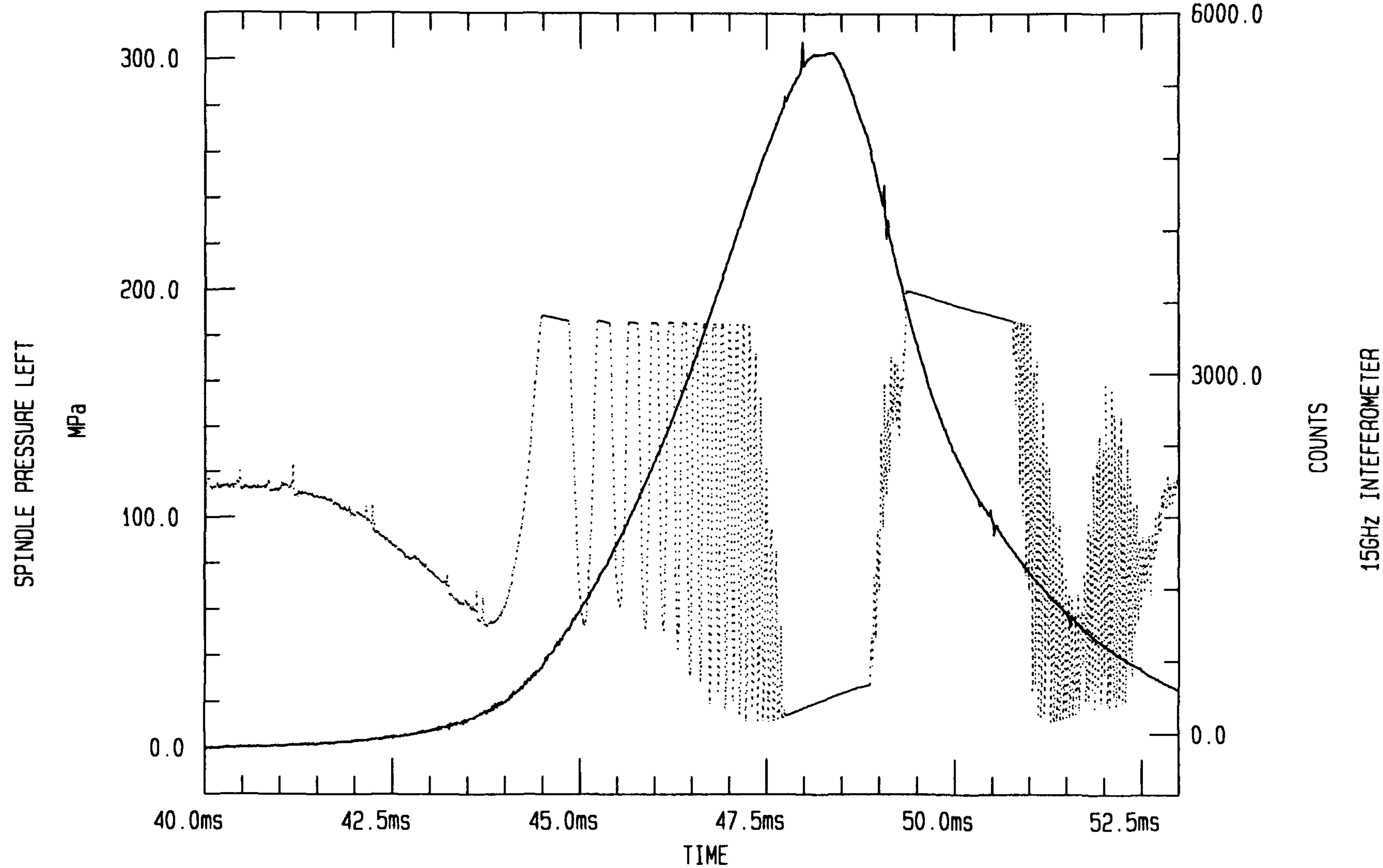

Figure 7. Spindle Pressure and Doppler Radar, Zone 8.

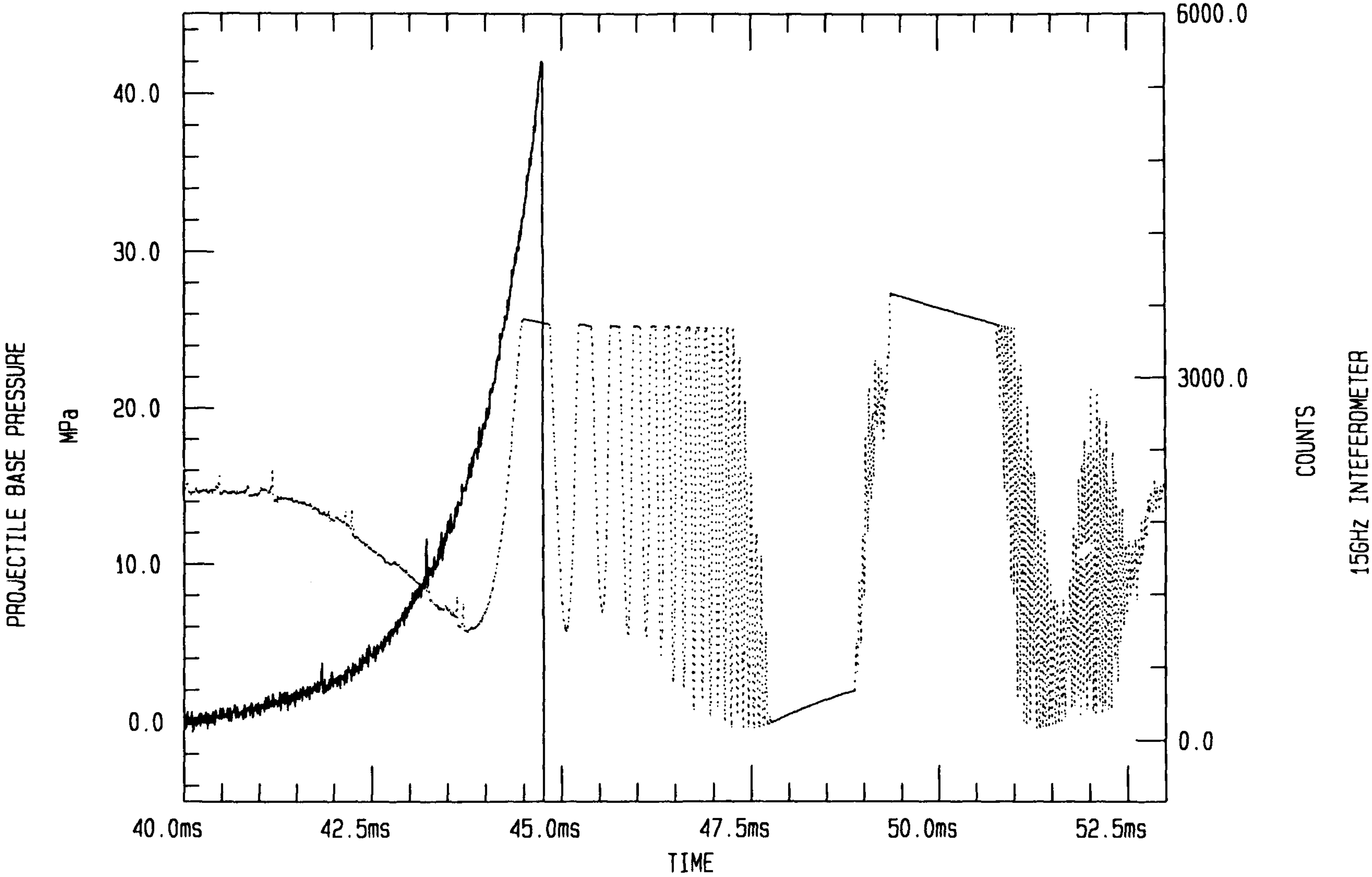

Figure 8. Onboard Base Pressure and Doppler Radar, Zone 8.

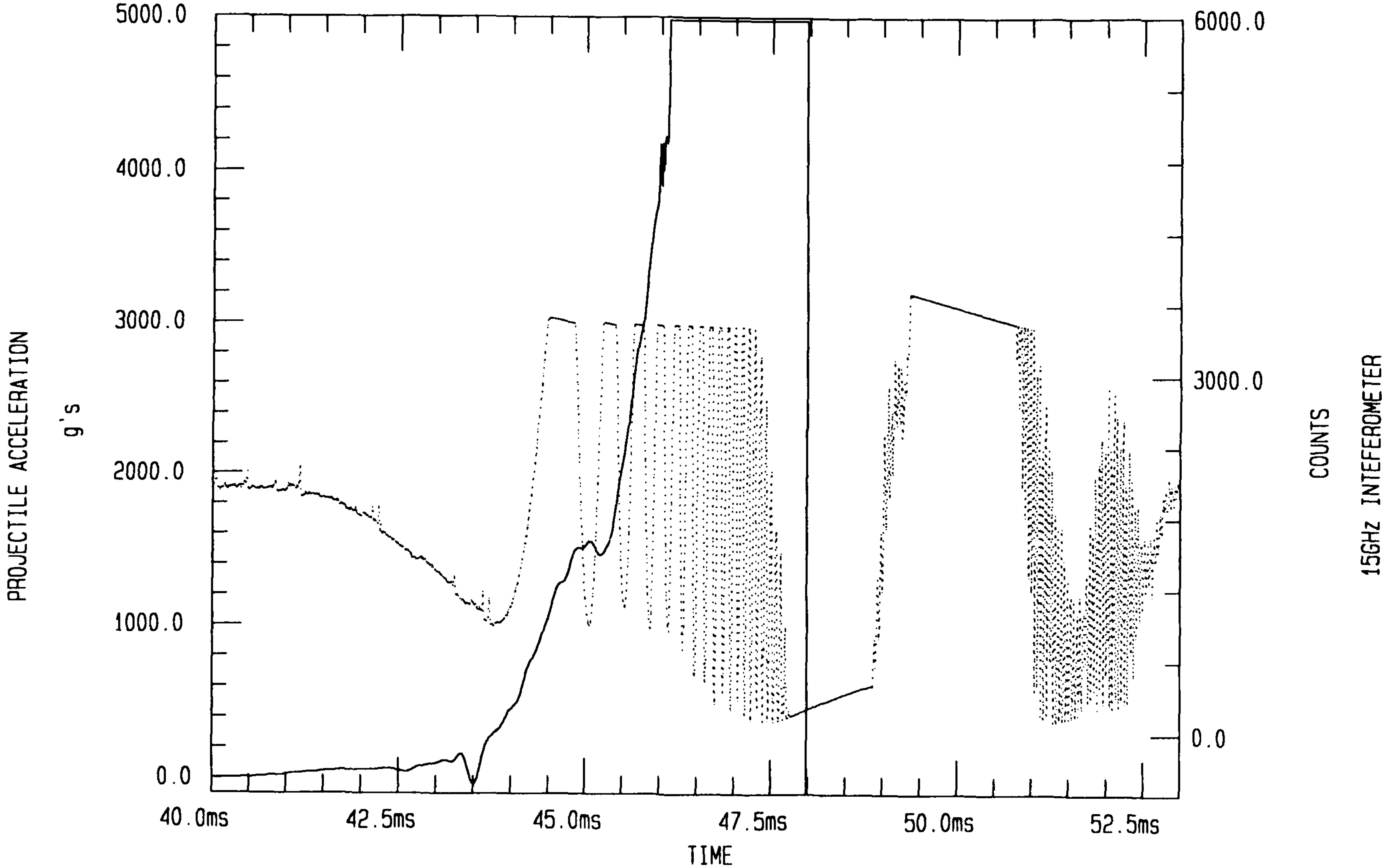

Figure 9. Onboard Acceleration and Doppler Radar, Zone 8.

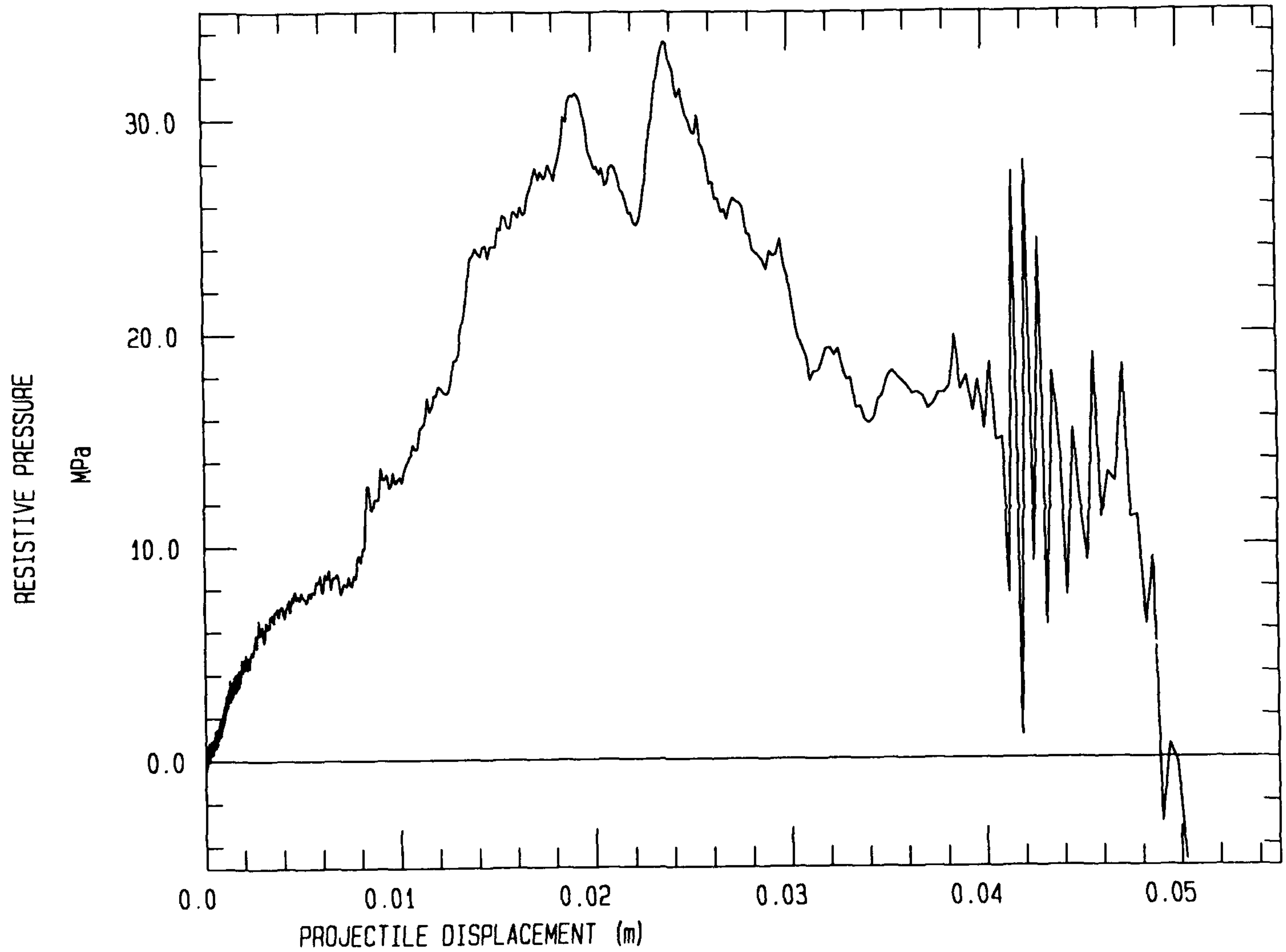

Figure 10. Resistive Pressure vs. Inbore Travel, Zone 5.

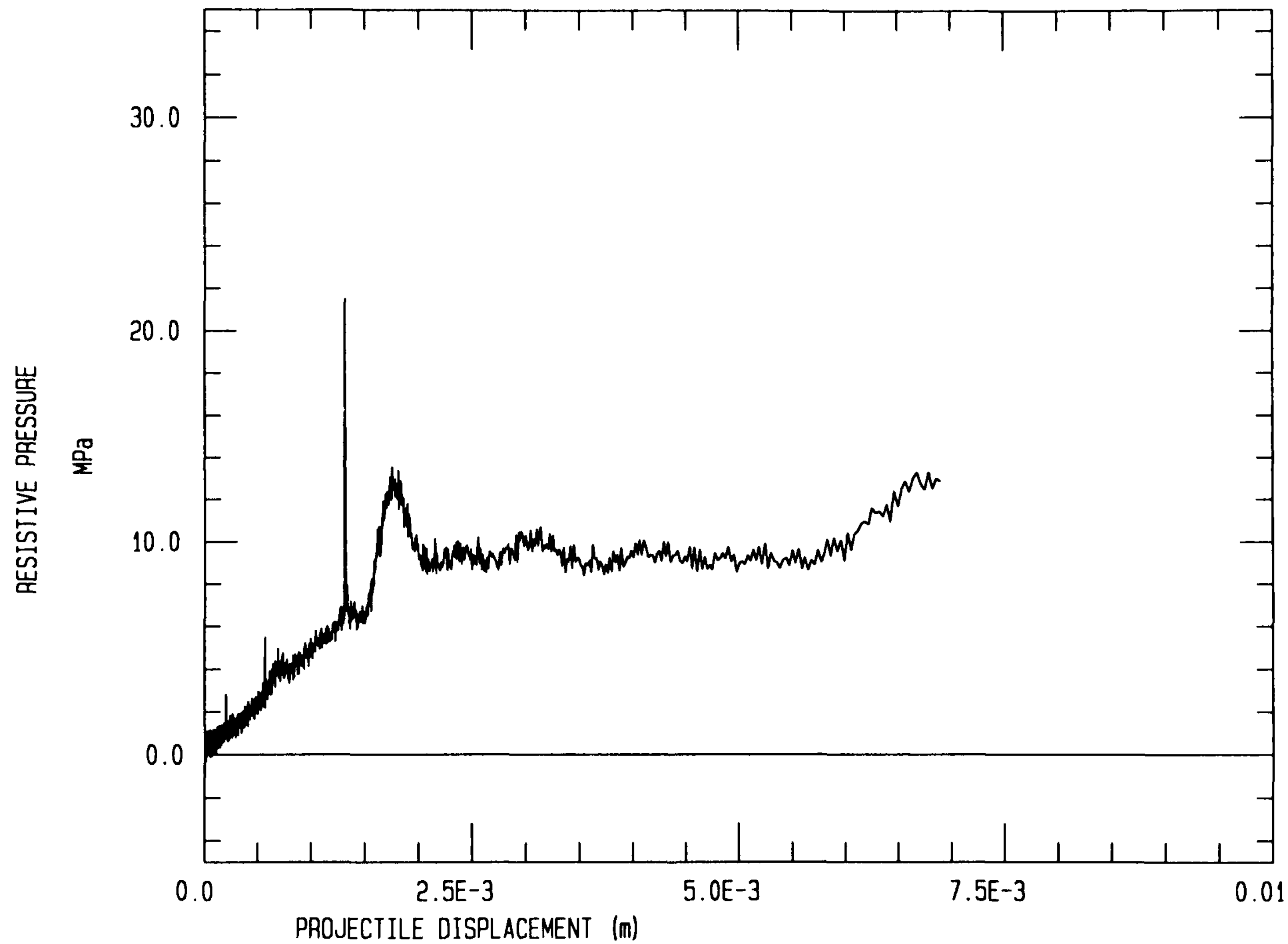

Figure 11. Resistive Pressure vs. Inbore Travel, Zone 8.

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